DOCKETED	
Docket Stamp Updated:	2/8/2022 2:12:22 PM
Docket Number:	19-SPPE-04
Project Title:	SJ2
TN #:	241480
Document Title:	Ada E Márquez Comments on CEQA Comment Letter Appendix A Ref (7 of 8)
Description:	Due to docket staff error, the document was docketed on February 7, 2022, not February 8, 2022.
Filer:	System
Organization:	Ada E. Márquez
Submitter Role:	Public
Submission Date:	2/8/2022 12:01:45 PM
Docketed Date:	2/7/2021

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Docket Number:	19-SPPE-04
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Description:	N/A
Filer:	System
Organization:	Ada E. Márquez
Submitter Role:	Public
Submission Date:	2/8/2022 11:17:50 AM
Docketed Date:	2/8/2022

Comment Received From: Ada E. MÃ¡rquez
Submitted On: 2/8/2022
Docket Number: 19-SPPE-04

Ada E MÃ¡rquez Comments - CEQA Comment Letter Appendix A Ref (7 of 8)

Additional submitted attachment is included below.

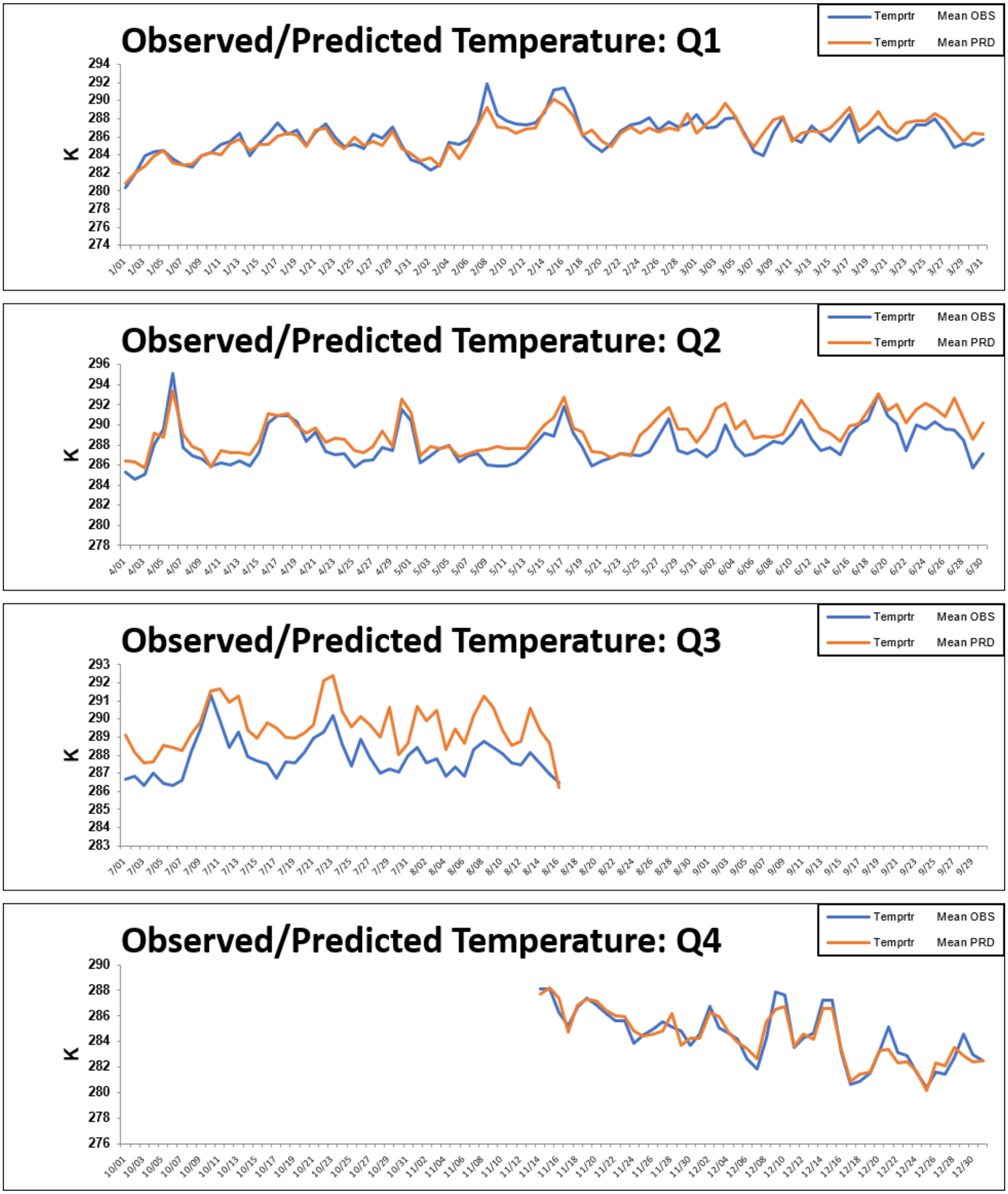


Figure C3: Daily time series of observed and simulated temperatures at West Oakland for 2016.

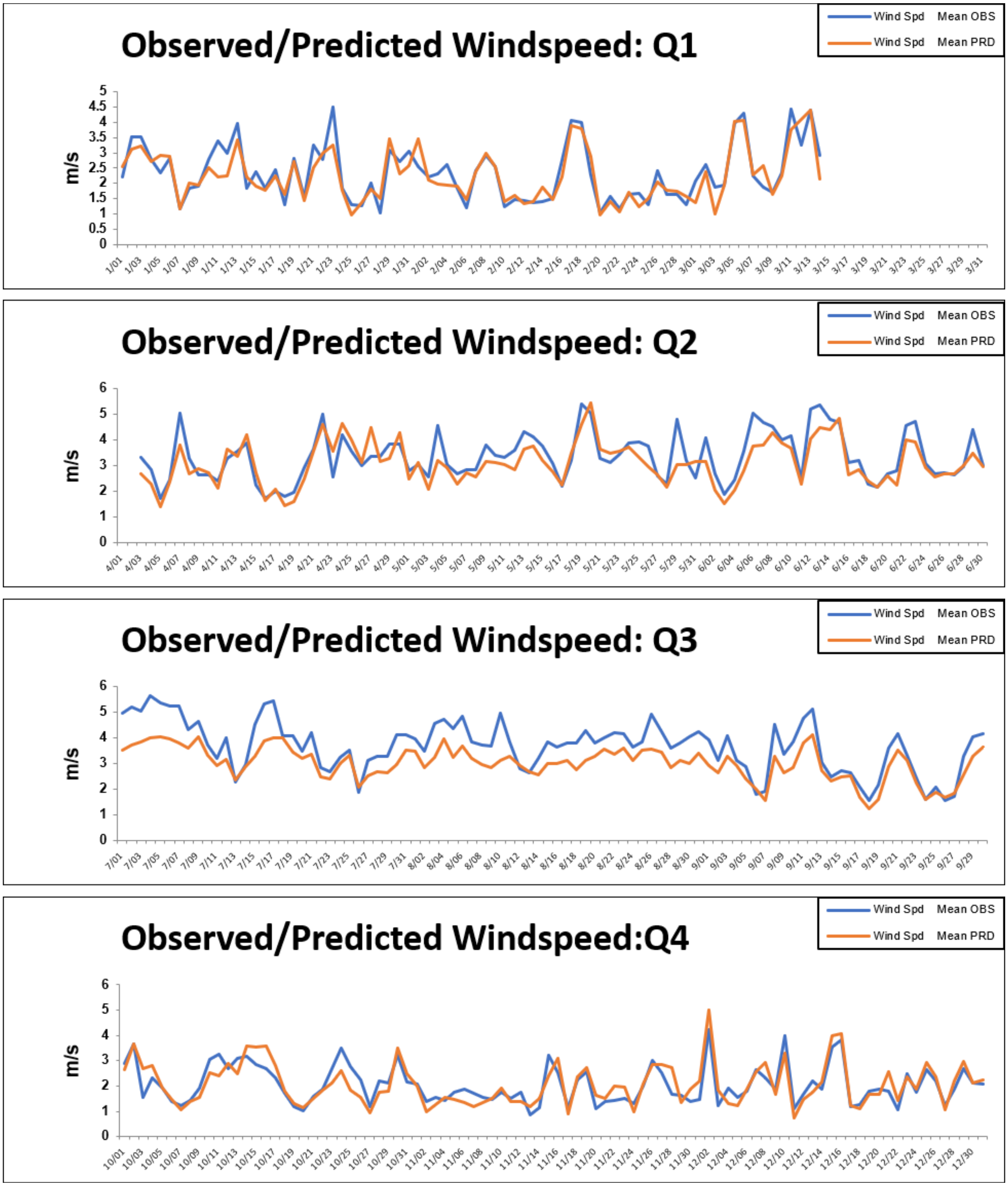


Figure C4: Daily time series of observed and simulated wind speed at Vallejo for 2016.

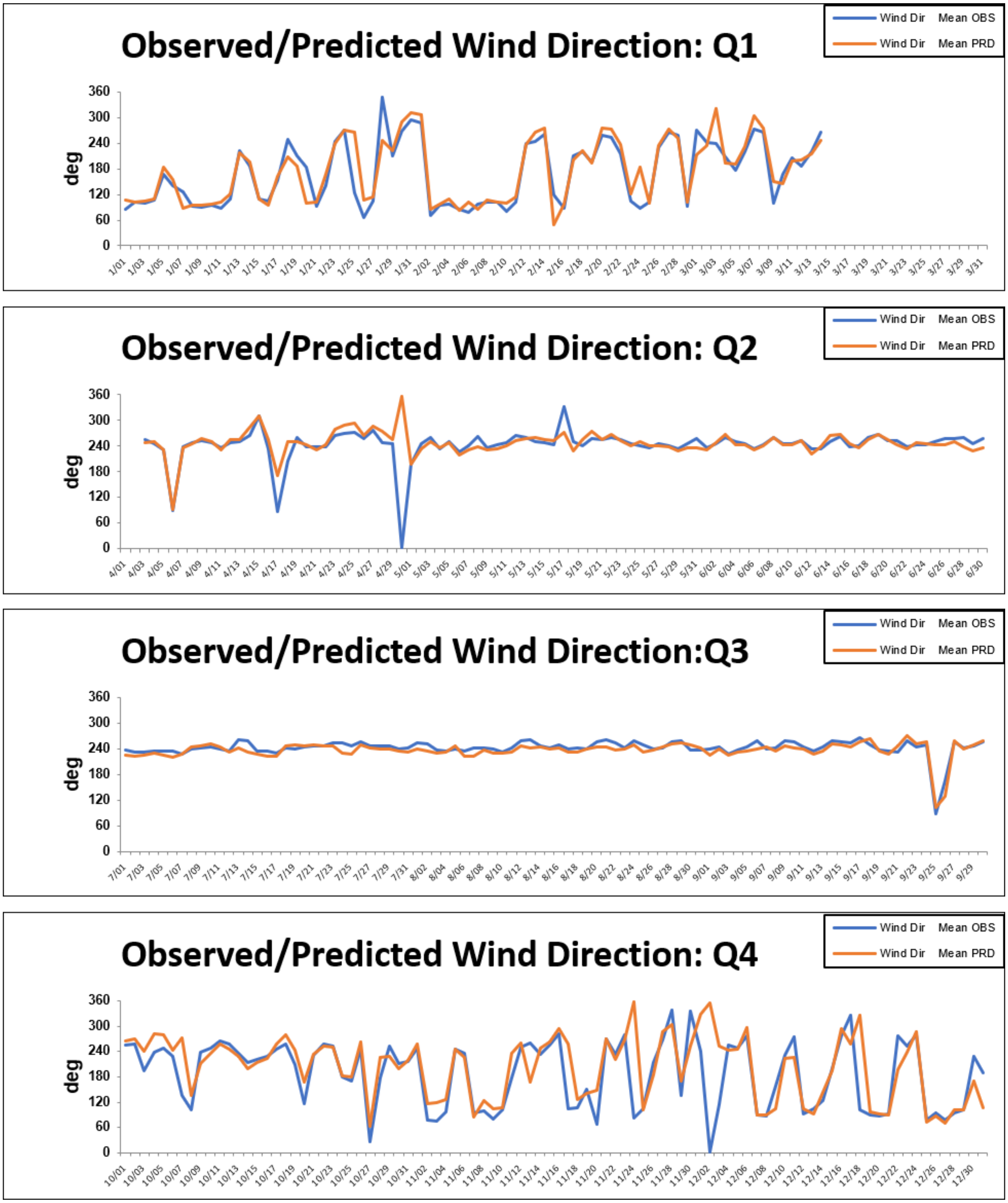


Figure C5: Daily time series of observed and simulated wind direction at Vallejo for 2016.

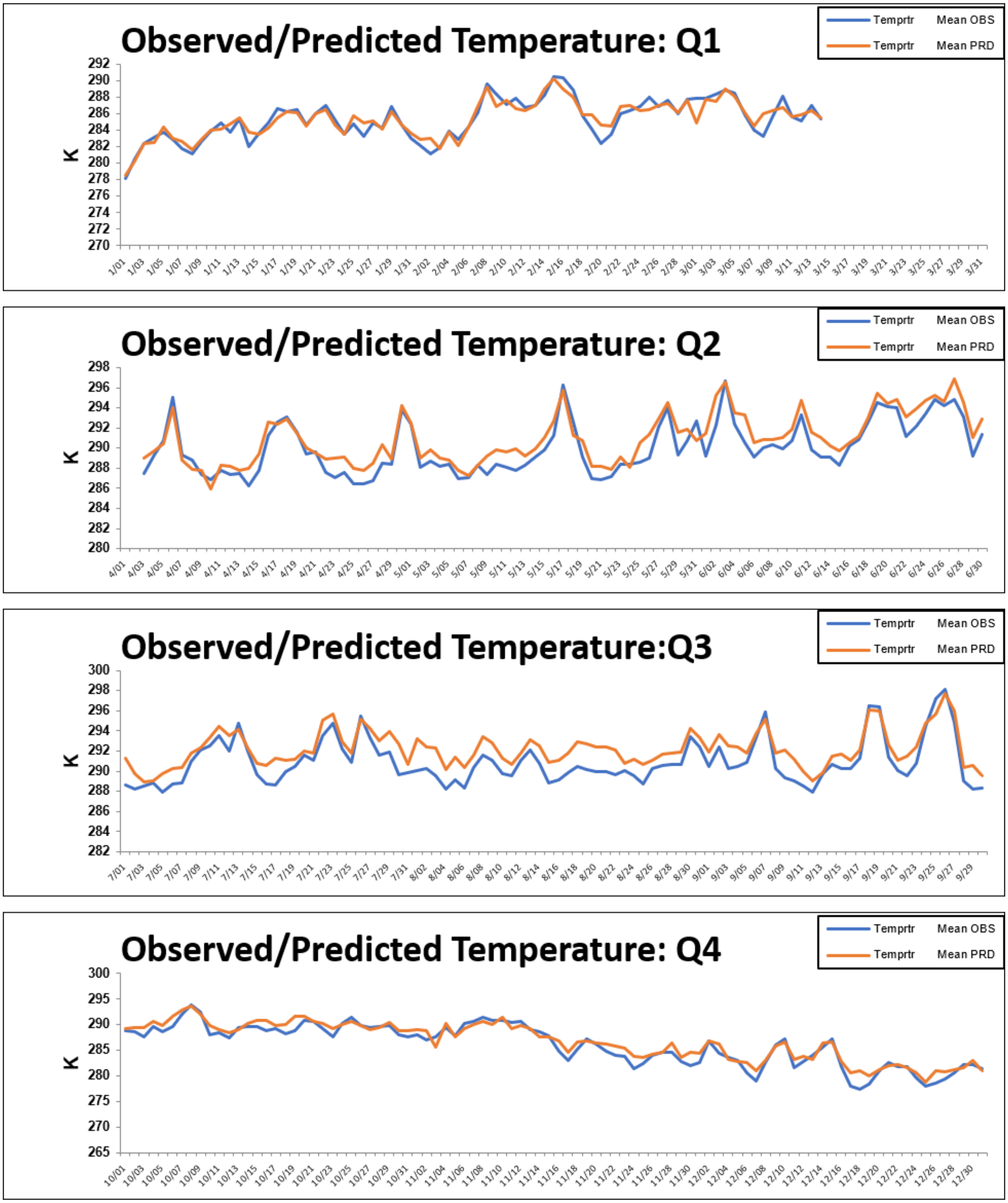


Figure C6: Daily time series of observed and simulated temperatures at Vallejo for 2016.

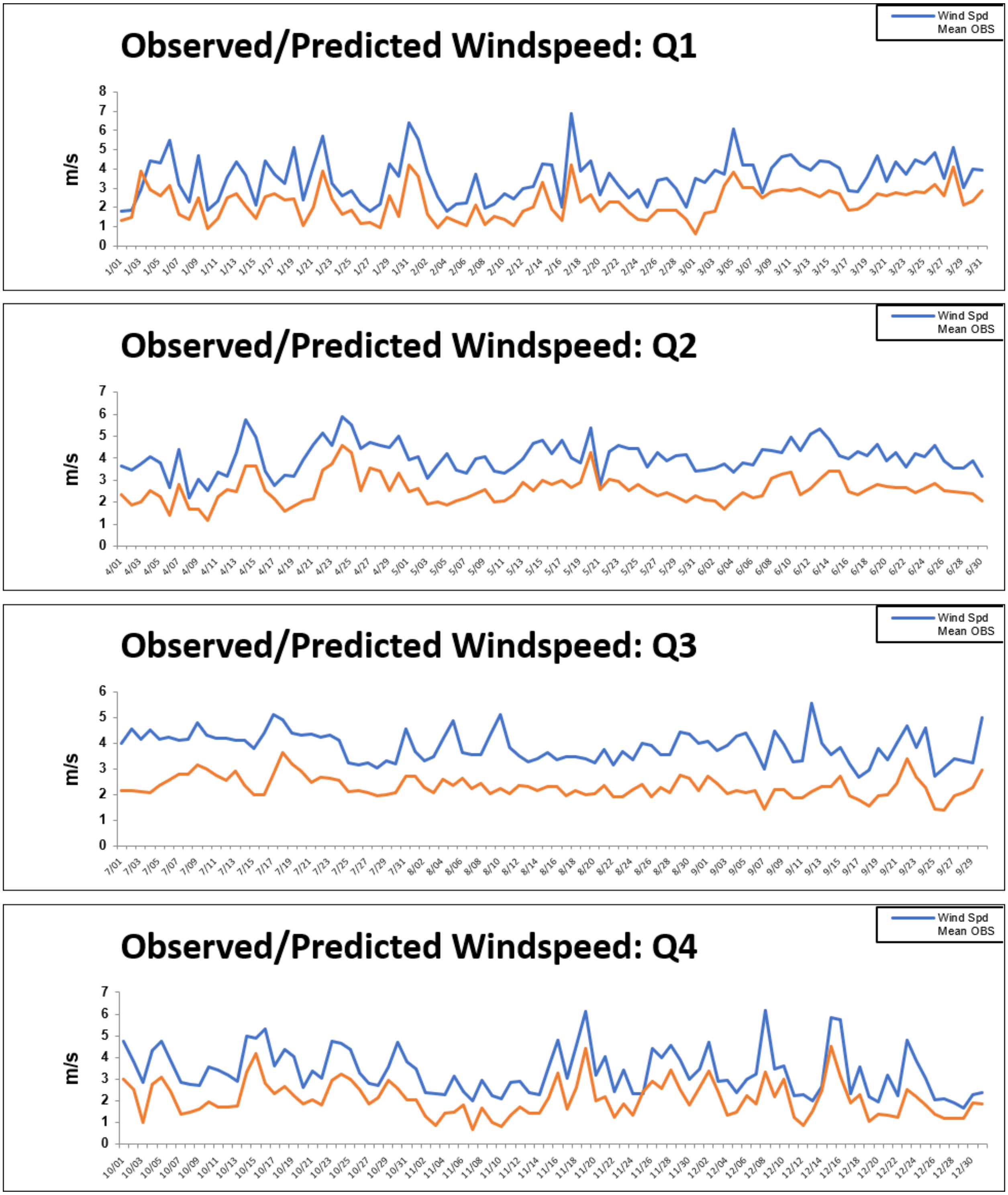


Figure C7: Daily time series of observed and simulated wind speed at San Jose for 2016.

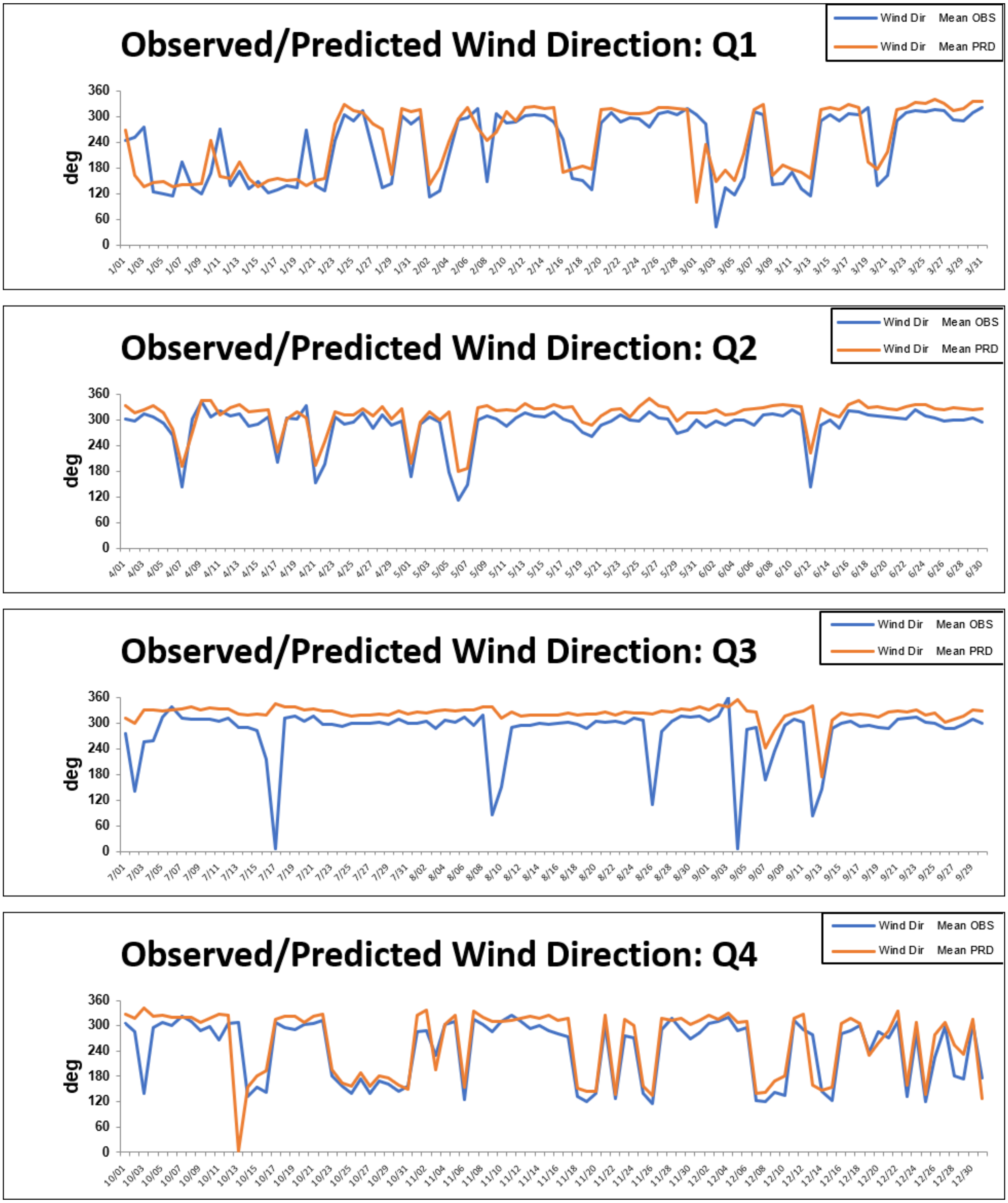


Figure C8: Daily time series of observed and simulated wind direction at San Jose for 2016.

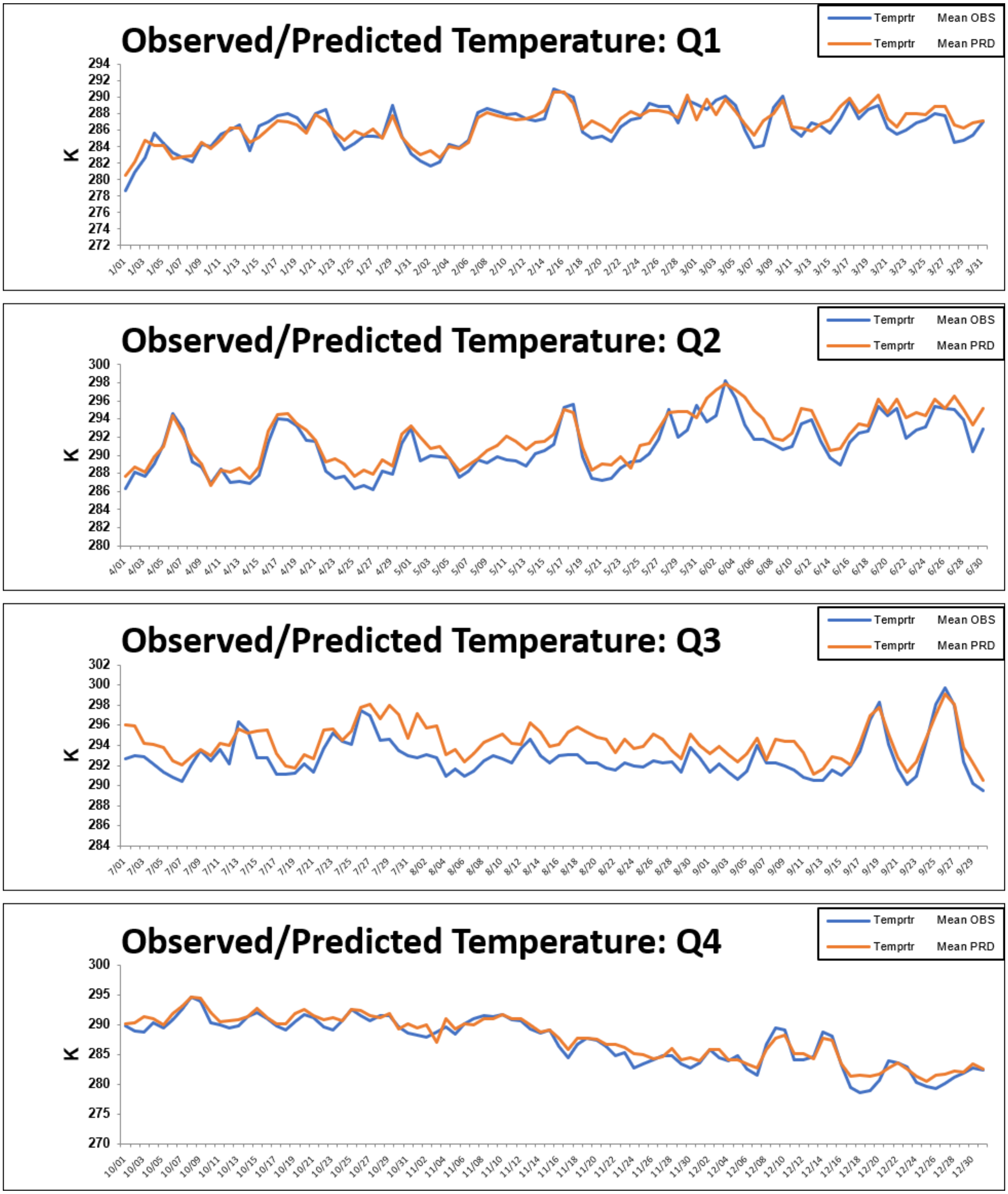


Figure C9: Daily time series of observed and simulated temperatures at San Jose for 2016.

C3. Evaluating WRF Against Upper Air Measurements

There were two upper air stations within the 1-km WRF modeling domain that were operating in 2016. One of them was in Oakland, where the National Weather Service made twice daily measurements at 00 GMT and 12 GMT (4:00 pm and 4:00 am PST, respectively) throughout the year. The other station was at Bodega Bay, where midday measurements were made from May through August, 2016. This was a temporary station established in support of the California Baseline Ozone Transport Study.

Outputs from the 1-km WRF model were compared against measurements at both stations. Day by day, simulations matched observations exceptionally well. Figures C10 and C11 show simulated and observed upper air meteorological data from one winter day (January 10, 2016 at 12 GMT) and from one summer day (June 4, 2016 at 12 GMT) at Oakland. Simulated temperature and dew point (dashed lines) follow observations (solid lines) very well.

Figure C12 shows observed and simulated temperatures at 1:00 pm at Bodega Bay. The simulated temperature matches observations very well.

These are randomly selected plots for the purpose of displaying observed vs. simulated meteorological parameters. They do not necessarily show the best or worst match between the simulation and observations.

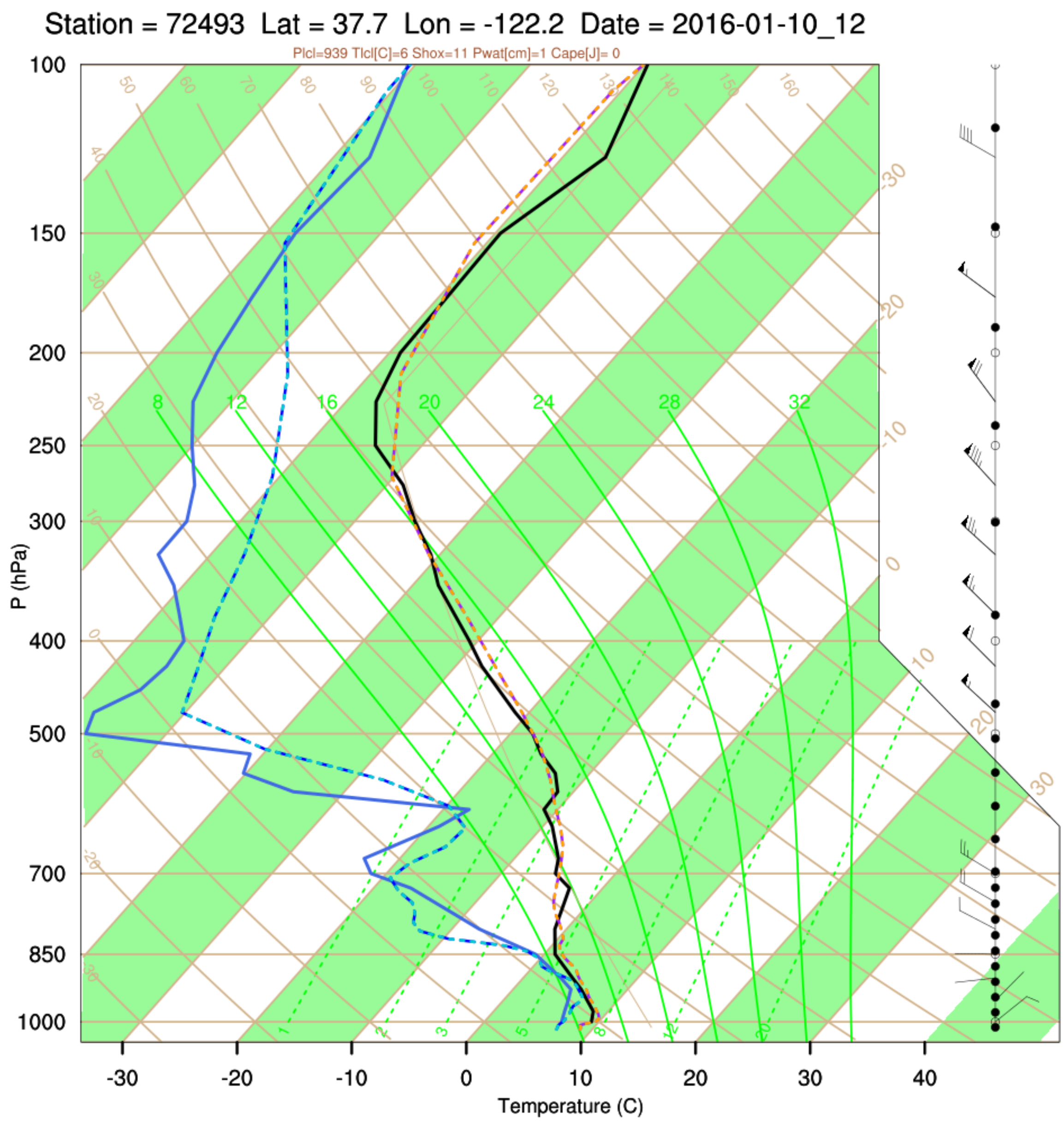


Figure C10: A skew-T plot showing simulated (dashed lines) and observed (solid lines) temperatures (orange and black) and humidity (blue) at Oakland on January 10, 2016 at 12 GMT. Observed wind barbs at pressure levels are shown on the right y-axis.

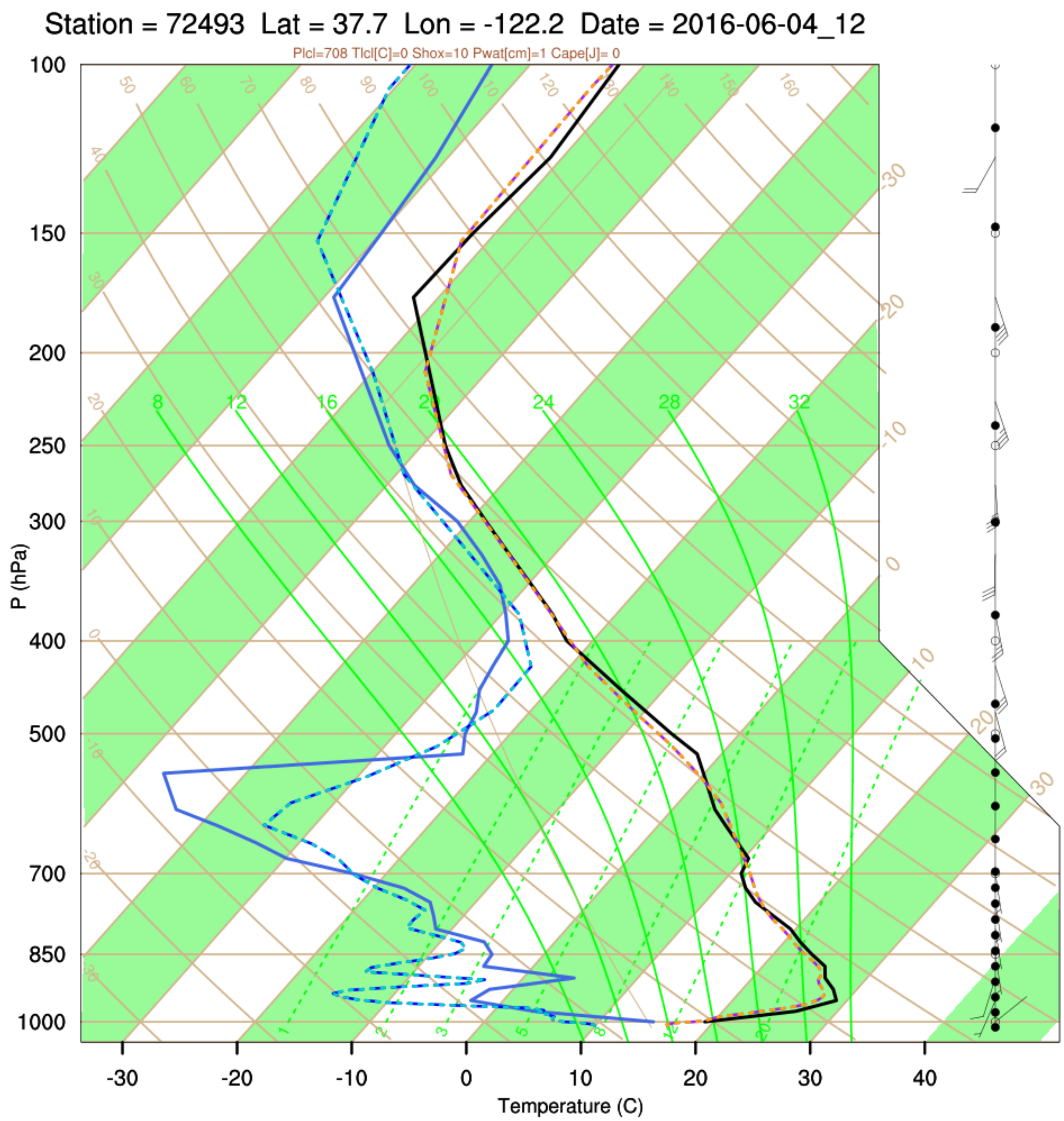


Figure C11: A skew-T plot showing simulated (dashed lines) and observed (solid lines) temperatures (orange and black) and humidity (blue) at Oakland on June 4, 2016 at 12 GMT. Observed wind barbs at pressure levels are shown on the right y-axis.

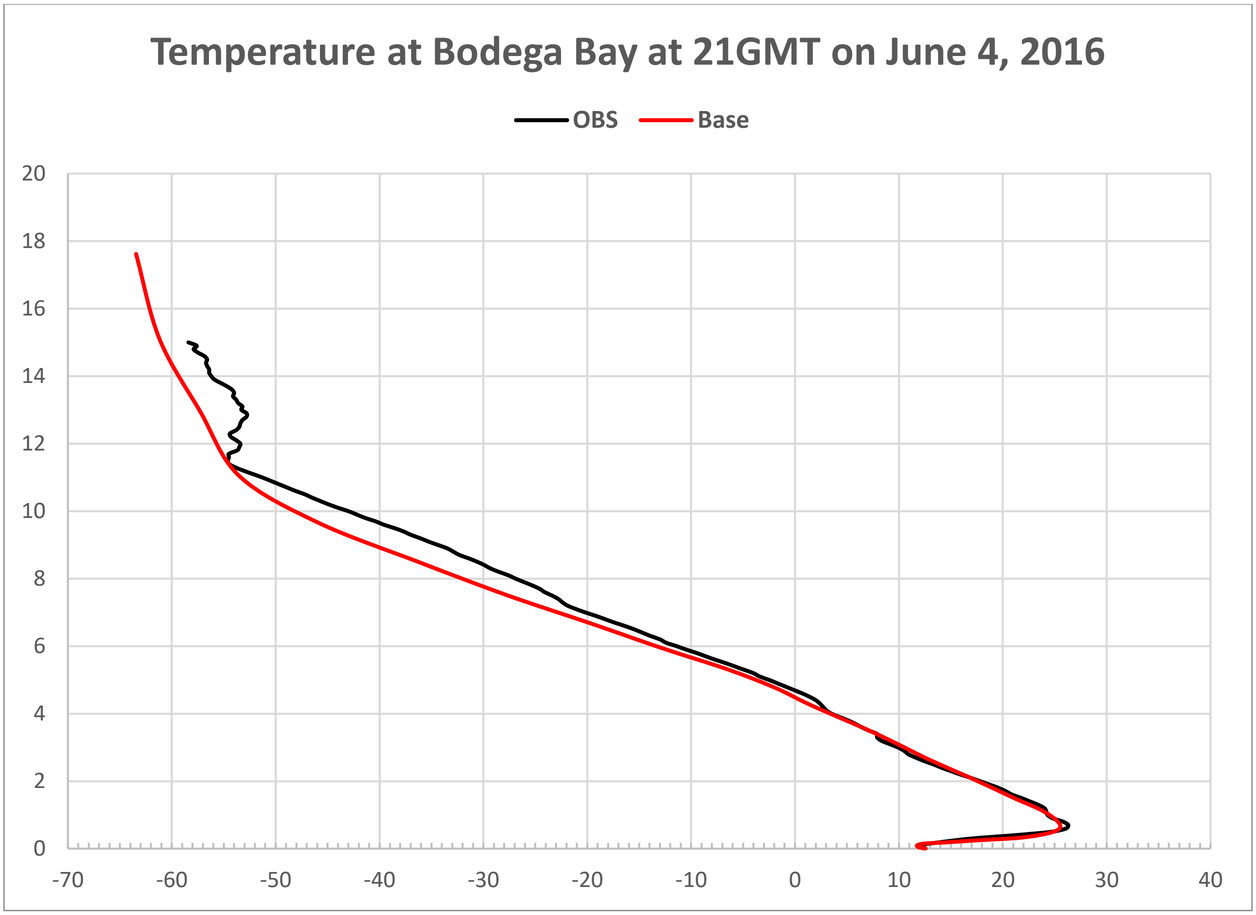


Figure C12: A plot showing simulated (red) and observed (black) temperatures at Bodega Bay at 1:00 pm PST.

Appendix D – Evaluation of the CMAQ Model

D1. Statistical Metrics

Table D1 shows statistical metrics used for CMAQ evaluation. Statistical metrics were calculated from paired daily observed and simulated $PM_{2.5}$ concentrations over quarterly and annual periods. Q1, Q2, Q3 and Q4 represent the 1st, 2nd, 3rd and 4th quarters, respectively. They are defined as January-March, April-June, July-September and October-December.

Table D1. Quarterly and annual statistical model performance metrics.

Metric	Definition[1]	Q1	Q2	Q3	Q4	Annual
Mean bias (MB, μg/m³)	$\frac{1}{N}\sum(P_i - O_i)$	2.3	-0.3	-1.2	0.4	0.3
Mean error (ME, μg/m³)	$\frac{1}{N}\sum\lvert P_i - O_i\rvert$	3.6	2.7	2.9	3.6	3.2
Root mean square error (RMSE, μg/m³)	$\sqrt{\frac{1}{N}\sum(P_i - O_i)^2}$	5.5	3.4	3.7	5.3	4.6
Fractional bias (FB, %)	$100 \times \frac{2}{N}\sum\frac{P_i - O_i}{P_i + O_i}$	23%	5%	-8%	4%	6%
Fractional error (FE, %)	$100 \times \frac{2}{N}\sum\frac{\lvert P_i - O_i\rvert}{P_i + O_i}$	40%	40%	43%	41%	41%
Normalized mean bias (NMB, %)	$100 \times \frac{\sum(P_i - O_i)}{\sum O_i}$	30%	-4%	-16%	4%	4%
Normalized mean error (NME, %)	$100 \times \frac{\sum\lvert P_i - O_i\rvert}{\sum O_i}$	47%	38%	39%	42%	42%
Correlation coefficient (r)	$\frac{\sum[(P_i - \overline{P})(O_i - \overline{O})]}{\sqrt{\sum(P_i - \overline{P})^2 \sum(O_i - \overline{O})^2}}$	0.69	0.35	0.32	0.61	0.56

[1] The summations are taken over all pairs of predictions (P_i) and valid observations (O_i) by site and day, and N is the total number of data pairs. Overbars represent means over the N data.

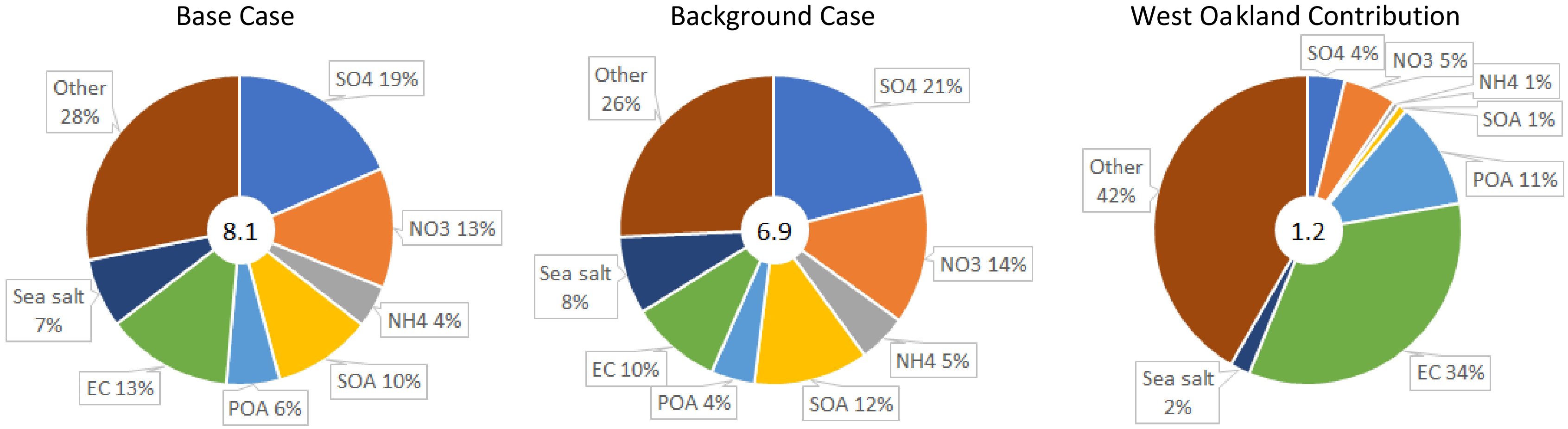
The annual mean bias in simulated $PM_{2.5}$ concentrations is 0.3 μg/m³. On a quarter by quarter basis, the mean bias ranges from -0.3 to 2.3 μg/m³. Among the quarters, Q1 has the highest bias. As explained in the main text, the model is significantly overestimating $PM_{2.5}$ during winter months, especially in February. Possible reasons for the overestimation are under investigation.

Overall, the model shows acceptable $PM_{2.5}$ performance, meeting the goals by Boylan and Russell (2006) and criteria by Emery et al. (2017) for the whole year as well as all 4 quarters.

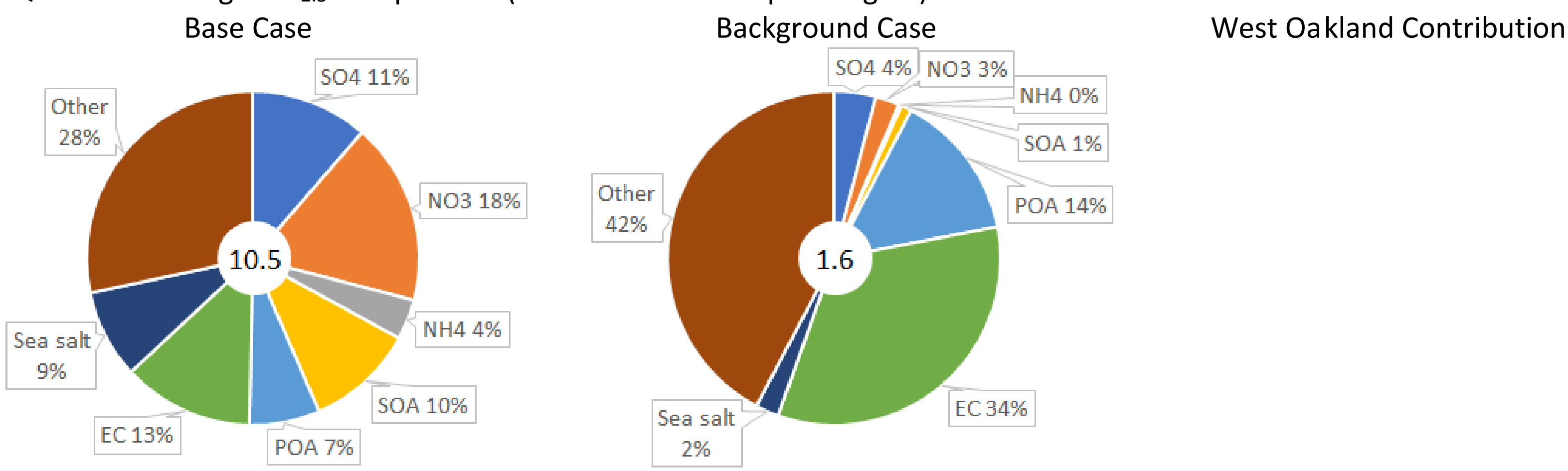
D2. West Oakland $PM_{2.5}$ Composition

Figure D1 shows annual and quarterly average $PM_{2.5}$ compositions over the West Oakland receptor domain for the base and control (i.e., a simulation without West Oakland's anthropogenic emissions) cases as well as the West Oakland contributions (i.e., the difference between the base and control cases). The "Other $PM_{2.5}$" fractions (primary $PM_{2.5}$ mass other than carbonaceous material and sea salt; mostly fugitive dust in this region) are generally the largest component except for the 3rd quarter, where sulfate is the dominant $PM_{2.5}$ component. Secondary $PM_{2.5}$ fractions (ammonium sulfate, ammonium nitrate, and secondary organic aerosol) account for approximately half of total $PM_{2.5}$ mass (ranging from 41% to 63%). The base and control cases exhibit similar $PM_{2.5}$ compositions, indicating that the regional background influence is dominating. The West Oakland contributions are heavily weighted by primary fractions (84% to 93%) from the local sources.

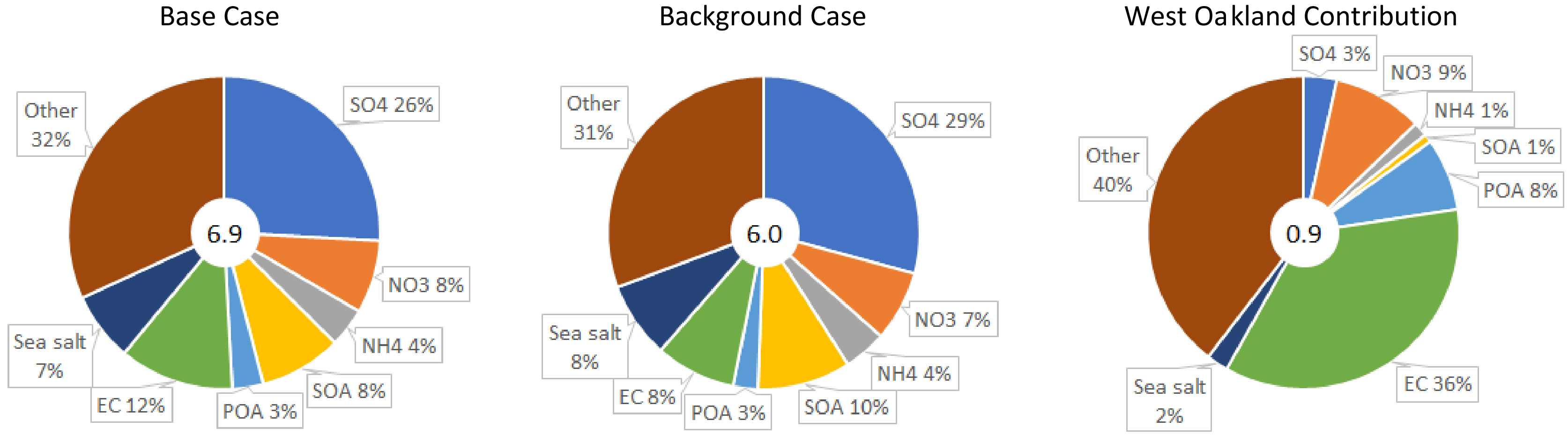
(a) Annual Average $PM_{2.5}$ Composition (West Oakland Receptor Region)



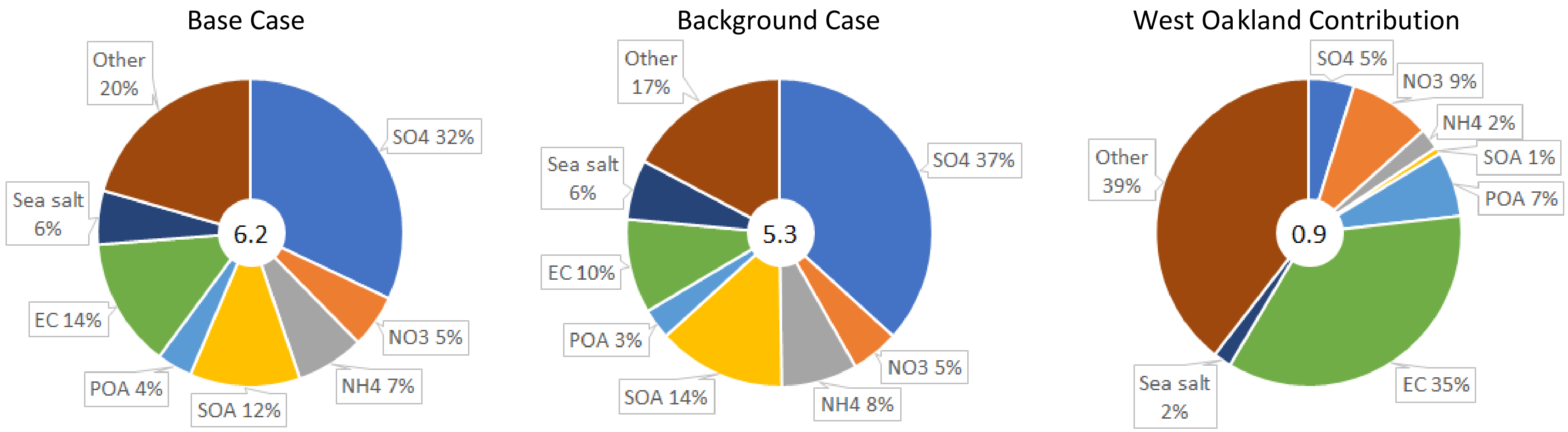
(b) Quarter 1 Average $PM_{2.5}$ Composition (West Oakland Receptor Region)



(c) Quarter 2 Average $PM_{2.5}$ Composition (West Oakland Receptor Region)



(d) Quarter 3 Average $PM_{2.5}$ Composition (West Oakland Receptor Region)



(e) Quarter 4 Average $PM_{2.5}$ Composition (West Oakland Receptor Region)

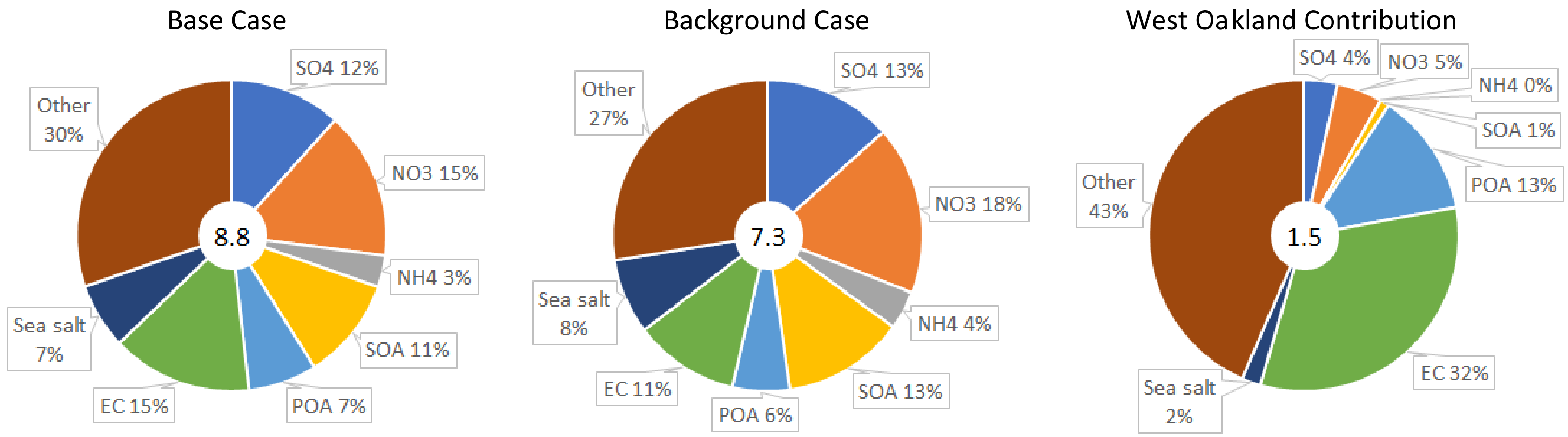


Figure D1: Annual and quarterly average $PM_{2.5}$ compositions over the West Oakland Receptor Region for the base and control cases and their differences (i.e., contributions from the West Oakland anthropogenic emissions). Numbers in the center are total $PM_{2.5}$ concentrations in $\mu g/m^3$.

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DOCKETED	
Docket Number:	19-SPPE-04
Project Title:	SJ2
TN #:	237463
Document Title:	Bay Area Air Quality Management District Comments - Air Quality Data Request
Description:	N/A
Filer:	System
Organization:	Bay Area Air Quality Management District
Submitter Role:	Public Agency
Submission Date:	4/15/2021 2:35:49 PM
Docketed Date:	4/15/2021

Comment Received From: Bay Area Air Quality Management District
Submitted On: 4/15/2021
Docket Number: 19-SPPE-04

Air Quality Data Request

Additional submitted attachment is included below.

APRIL 12, 2021

MOBILE SOURCE HEALTH RISK – YR2014

RECEPTOR ID: PMI 37.4230326377571, 121.928701731414

	Type	Risk
Cancer	Highway	46.597
	Major Street	1.529
	Rail	0.648
PM2.5	Highway	0.909
	Major Street	0.037
	Rail	0.001

RECEPTOR ID: MESR 37.4225072385361, 121.90639731508

	Type	Risk
Cancer	Highway	15.808
	Major Street	1.648
	Rail	0.493
PM2.5	Highway	0.333
	Major Street	0.039
	Rail	0.001

RECEPTOR ID: MEIW 37.4230326377571, 121.928701731414

	Type	Risk
Cancer	Highway	46.597
	Major Street	1.529
	Rail	0.648
PM2.5	Highway	0.909
	Major Street	0.037
	Rail	0.001

RECEPTOR ID: MEIR 37.4185964451612, 121.927529766093

	Type	Risk
Cancer	Highway	15.178
	Major Street	2.193
	Rail	0.559
PM2.5	Highway	0.311
	Major Street	0.053
	Rail	0.001

METHOD/DATA

Cancer risk and PM2.5 were modeled in AERMOD for all highways/freeways and roadways >30,000 AADT (annual average daily traffic) and rail in 20 x 20 meter grid cells. The files incorporate AADT for that highway using EMFAC 2014 data for fleet mix and includes OEHHA's 2015 Air Toxics Hot Spots Guidance methods.

The Air District assigned vehicle counts on each link using information from the California Department of Transportation (Caltrans) and the Metropolitan Transportation Commission (MTC) for all roads with greater than 30,000 AADT. Traffic counts for state highways are from 2014 while surface streets AADT reflect 2015 counts when available, with older counts from 2010 through 2013 if data were missing. Sources of data used for the activity data are described below.

- State highway activity on the state highway system was represented using 2014 AADT counts from Caltrans. AADT values represent the total traffic volume for the year divided by 365 days, and these counts are reported for state highway segments defined using milepost values. Caltrans provides AADT data for total traffic and for trucks only, with trucks classified by axle number (the two-axle class excludes pickups and vans with only 4 tires).

- Daily traffic counts on surface streets were obtained from Metropolitan Transportation Commission (MTC) which receives roadway counts from local agencies as part of the Highway Performance Monitoring System (HPMS) with the exception of Santa Rosa, which posts the AADT on their web page.

- Year 2014 traffic volumes were forecast to 2017 using county-level growth factors from the California Air Resources Board's (ARB) EMFAC2014 mobile source emissions model. EMFAC2014 was run for all Bay Area counties for 2014, and vehicle miles of travel (VMT) output data were used to calculate the growth factors needed to project 2014 traffic volumes to 2017.

THRESHOLDS OF SIGNIFICANCE BASED ON CEQA GUIDANCE:

Local community risk and hazard impacts are associated with Toxic Air Contaminants (TACs) and fine particulate matter with an aerodynamic resistance diameter of 2.5 micrometers or less ($PM_{2.5}$) because emissions of these pollutants can have significant health impacts at the local level. If emissions of TACs or $PM_{2.5}$ exceed any of the Thresholds of Significance, a project would result in a significant impact.

	SIGNIFICANCE THRESHOLD (CUMULATIVE)
CANCER	100 in a million
AMBIENT PM2.5	0.8 ug/m^3

FID	OBJECTID	FACID	Name	Address	City	St	Zip	County	Cancer (per million)	Hazard	PM_2.5 (ug/m3)	Type	Latitude	Longitude	x	y
1511	1,511	13289	Los Esteros Critical Energy Facility	800 Thomas Foon Chew Way	San Jose	CA	95134	Santa Clara	63.63	0.4	122.75	Turbine (5), Fire Pump (1), Boiler (4), Cooling Tower (1)	37.426	-121.933	-1.4E+07	4498686
1538	1,538	13399	KLA Tencor	Technology Drive	Milpitas	CA	95035	Santa Clara	84.53	0.16	0.35	Generator (6), Solvent Cleaning (4), Boiler (3)	37.419	-121.93	-1.4E+07	4497664
1936	1,936	14171	Pacific Gas and Electric	66 Ranch Drive	Milpitas	CA	95035	Santa Clara			0.0029	Natural Gas Generator (2)	37.426	-121.925	-1.4E+07	4498636
5020	5,020	21154	Fairfield Development, LP	501 Murphy Ranch Rd	Milpitas	CA	95035	Santa Clara	0.32	0	0	Generators	37.418	-121.928	-1.4E+07	4497552
7955	7,955	111148	McCarthy Ranch Chevron & Carwash	367 Cypress Dr	Milpitas	CA	95035	Santa Clara	0.03	0	0	Gas Dispensing Facility	37.421	-121.922	-1.4E+07	4498016

A Path Forward for PM Regulation in the San Francisco Bay Area

by Stan Hayes and Jeff McKay

A summary of the findings from a report conducted by the San Francisco Bay Area Air Quality Management District to identify measures to help reduce particulate matter (PM) emissions, particularly in the most impacted communities that historically have been most burdened by air pollution and discrimination.

Under the U.S. Clean Air Act, relying on the latest and best science in consultation with scientific experts on the Clean Air Scientific Advisory Committee (CASAC), the U.S. Environmental Protection Agency (EPA) must set National Ambient Air Quality Standards (NAAQS) to protect the public health and welfare. In late 2018, however, the then-current EPA leadership dismissed CASAC's Particulate Matter (PM) Review Panel science experts without notice, leaving their advisory work undone. In December 2020, EPA took final action to reject the latest PM science and the advice of their own staff by refusing to tighten PM standards. Though now under reconsideration by the current EPA, that action will take some time to revisit.

Meanwhile, in the San Francisco Bay Area, it was left to the Bay Area Air Quality Management District to act on its own on behalf of the people of the Bay Area. The Air District and its Advisory Council determined that PM is a key air quality public health risk driver, both as a criteria pollutant, $PM_{2.5}$, and as a toxic air contaminant in the form of diesel PM. Because of this importance, the body of PM scientific research and the guidance of PM experts is crucial to local agencies in setting priorities and grounding new and innovative approaches to reduce PM exposure.

The Air District Board appoints an Advisory Council, which consists of seven members with experience in the fields of air pollution, climate change, or the health impacts of air pollution. Following three years of intense wildfire smoke PM, the Air District's long-standing focus on diesel PM emissions, and the conclusion that PM is the dominant health risk driver in Bay Area air quality, the Air District asked the Advisory Council to provide its assessment of the latest and best PM health science. Building on that science, the Advisory Council was asked to assist in identifying further PM measures that would most move the public health needle, particularly in the most impacted communities, often people of color who historically have been most burdened by air pollution and discrimination.

The Process

For more than 18 months, the Air District and the Advisory Council together sought a path forward to identify a strategy to further reduce PM in the Bay Area, above and beyond attainment of current PM air quality standards, and above and beyond PM reduction efforts already underway. In October 2019, an all-day PM health effects state-of-the-science symposium was convened by the Air District and the Advisory Council, attended by more than 300 in-person and online participants. The symposium included former EPA Administrator Gina McCarthy and a number of nationally recognized PM experts, including leading experts involved in PM NAAQS development at the federal level. In December 2019, the Advisory Council met and further deliberated symposium presentations and panel discussions.

To ensure that highly impacted communities had a voice, the Air District joined with community leaders to form a PM Community Design Team, consisting of representatives of different community organizations and other leaders in highly impacted communities. In February 2020, a community PM discussion was conducted among Air District staff and 30 attendees from local organizations, co-led by the Air District and the PM Community Design Team.

In May 2020, the Advisory Council received presentations from spokespersons for the PM Community Design Team, as well as extensive public comment. In July 2020, the Advisory Council heard presentations from representatives of regulated industries. The Advisory Council's deliberations of its findings and recommendations began during the second half of its July 2020 meeting, continued in October and November 2020, and concluded with the adoption of a final report and its presentation to the Air District Board in December 2020.

Report Findings and Recommendations

The Advisory Council's 568-page final report[1] makes 45 separate findings and recommendations and includes a

In 2019, the Air District held an all-day PM health effects state-of-the-science symposium, which was attended by more than 300 in-person and online participants and included former EPA Administrator Gina McCarthy, as well as a number of nationally recognized PM experts.

collection of presentations made to the Advisory Council, interim status reports documenting the Advisory Council's progress, and an annotated bibliography of supporting scientific references. (A full list of findings and recommendations is available online at http://www.baaqmd.gov/~/media/files/board-of-directors/advisory-council/2020/ac_particulate_matter_reduction_strategy_report.pdf?la=en&rev=570867c8b25e4ca0b2f93f80c4c1ef02.) Panel presentations were also made at the 2020 and 2021 Air & Waste Management Association Annual Meetings.[2,3]

Findings and recommendations are divided into three parts: PM reduction statements on the current state of PM science and the health risks of PM exposure; a framework for evaluating PM reduction strategies, setting forth important principles that together form a recommended framework for the Air District's evaluation of future PM reduction strategies; and a list of recommended actions to reduce PM, identifying a number of specific actions that could be taken, organized into categories that reflect key priorities in the PM reduction statements and the framework.

PM Reduction Statements

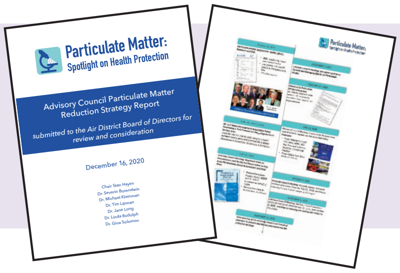
Among the most significant findings in the report are that:

1. PM is the most important health risk driver in Bay Area air quality;
2. Current PM standards are not health protective;
3. More stringent standards are urgently needed and could save many lives each year across the United States and in the Bay Area;
4. Further PM reductions will result in public health benefits;
5. Until previous EPA actions have been reconsidered and more stringent PM standards adopted, an Air District guideline "target" below the current PM standards is warranted to protect public health; and
6. Wildfire smoke PM is a serious contributor to PM health risk and will increase due to climate change.

Framework for Evaluating PM Reduction Strategies

The framework for evaluating PM reduction strategies places particular priority on the most heavily impacted communities, especially recognizing the Air District Board's resolution[4] affirming the Air District's commitment to diversity, equity, access, and inclusion. Among the most important recommendations in the framework are:

1. Move as quickly as possible to take maximal feasible action within the Air District's authority;
2. Prioritize those actions that are most effective in reducing PM exposure and improving public health and health equity in the most impacted areas;
3. Focus PM reduction in areas with elevated exposures, health vulnerability, increased impacts, and sensitive populations;



The 568-page final report makes 45 separate findings and recommendations and includes an annotated bibliography of supporting scientific references.

4. Address cumulative impacts in highly impacted communities by considering the combined effects of regional (Bay Area-wide), local (community-level), and localized hot-spot (block-level) sources; and
5. There is no single universal solution, thus requiring multiple source categories to be addressed with a wide range of emission reduction measures.

List of Recommended Actions

A total of 28 specific actions to reduce PM are provided in the List of Recommended Actions. These actions are grouped into four categories:

1. **More protective targets** (e.g., support establishment of more stringent PM air quality standards, set an Air District PM guideline target);
2. **Impacted communities** (e.g., develop PM strategic action plans for the most impacted communities, take maximum feasible action within District authority as quickly as possible, use best available methods, prioritize measures that are most effective, expand community PM exposure assessments, strengthen implementation and enforcement, include cumulative PM impacts in permitting);
3. **Wildfires** (e.g., further develop health protective strategies during wildfire episodes, support the conduct of more wildfire smoke health impact studies, deploy exposure reduction measures such as clean air shelters, personal protective equipment [PPE], high-efficiency particulate air [HEPA] filters for high-risk individuals); and
4. **Regional actions** (e.g., reduce vehicle miles traveled, make PM air quality data more accessible, expand use of active transportation [e.g., walking or bicycling], transit, land use, and telework, convert the built environment to all electric, require electric utilities in new construction).

Moving Forward

Aside from wildfire events, the Air District has made, and continues to make, significant progress in lowering PM levels in the Bay Area. As stated by the Air District's Chief Executive Officer Jack Broadbent in the report, "But there is still more to do. Now, more than ever, as we face rising temperatures, changing climates, and persistent inequity, the Air District's work is imperative to ensure a better quality of life for everyone in the Bay Area."[1]

The Advisory Council's work offers important input to the Air District's ongoing efforts, helping to provide a roadmap for future PM reductions in Bay Area air. This work assesses the latest and best PM health science, it supports the importance of the Air District's emphasis on environmental justice, it offers a framework for designing and evaluating PM control strategies, it highlights the need to focus on the most impacted communities, and it proposes a menu of possible actions to reduce PM.

In doing so, the Advisory Council's work will help the Air District set its future priorities and agenda, as well as further validating the Air District's leading-edge efforts to take independent action where and when needed. **em**

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Acknowledgment: The authors want to acknowledge and thank the Bay Area Air Quality Management District's Board of Directors, the many contributing staff and others, and Advisory Council Vice Chair Michael Kleinman and current and past members Severin Borenstein, Tim Lipman, Jane Long, Linda Rudolph, and Gina Solomon.

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Energy Implications of Economizer Use in California Data Centers

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ABSTRACT

In the US, data center operations currently account for about 61 billion kWh/y of electricity consumption, which is more than 1.5% of total demand. Data center energy consumption is rising rapidly, having doubled in the last five years. A substantial portion of data-center energy use is dedicated to removing the heat generated by the computer equipment. Data-center cooling load might be met with substantially reduced energy consumption with the use of air-side economizers. This energy saving measure, however, has been shown to expose servers to an order-of-magnitude increase in indoor particle concentrations with an unquantified increase in the risk of equipment failure. An alternative energy saving option is the use of water-side economizers, which do not affect the indoor particle concentration but require additional mechanical equipment and tend to be less beneficial in high humidity areas. Published research has only presented qualitative benefits of economizer use, providing industry with inadequate information on which to base their design decisions. Energy savings depend on local climate and the specific building-design characteristics. In this paper, based on building energy models, we report energy savings for air-side and water-side economizer use in data centers in several climate zones in California. Results show that in terms of energy savings, air-side economizers consistently outperform water-side economizers, though the performance difference varies by location. Model results also show that conventional humidity restrictions must by relaxed or removed to gain the energy benefits of air-side economizers.

Introduction

Data centers are computing facilities that house the electronic equipment used for data processing, networking and storage. Rapid growth in computational demand emerging from various sectors of the economy is causing strong rates of increase in servers and IT-related hardware (IDC 2007). Server performance has doubled every two years since 1999, leading to increasingly higher densities of heat dissipation within data centers (Belady 2007). A substantial proportion of energy consumption in data centers is dedicated to the cooling load associated with electronic power dissipation (Tschudi et al. 2003). A recent study estimates that US data centers account for 61 billion kWh or 1.5% of the nation's annual electricity consumption (US DOE 2007a). This corresponds to an electricity bill of approximately $4.5 billion in 2006 (EPA 2007). The environmental impact is substantial because 70% of the electricity in US is generated in power plants that burn fossil fuel (EIA 2007). Improved data center cooling technologies have the potential to provide significant energy savings. Cost savings and environmental benefits might also accrue.

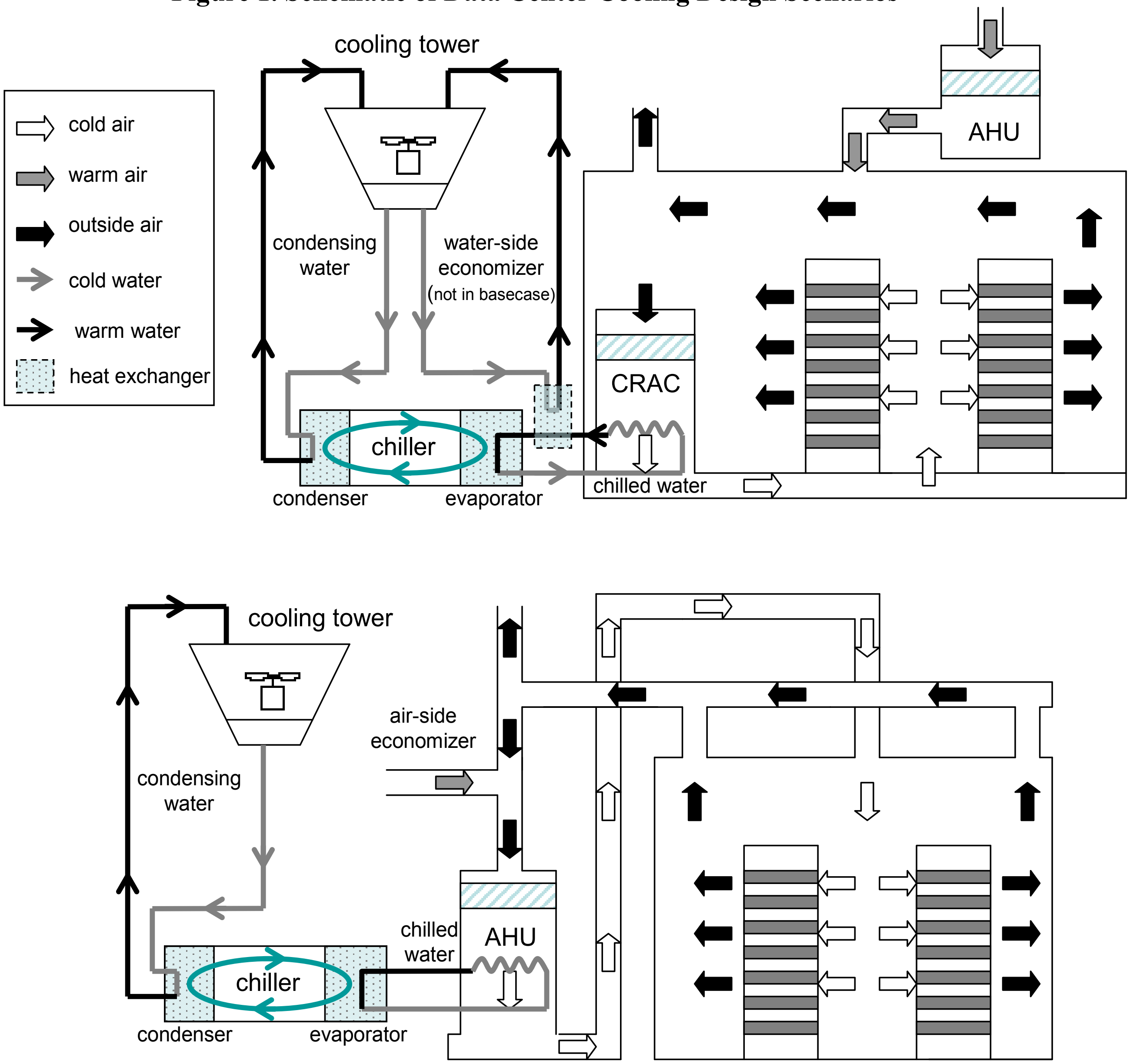
A typical data center consists of rows of tall (2 m) cabinets or racks in which the servers, data storage and networking equipment are vertically arrayed. The cooling of data-center equipment is accomplished using computer room air conditioners (CRACs), which supply cold air to a raised-floor plenum beneath the racks. The CRAC system air handler is placed on the data center floor while chilled water in transported from compressor-based chillers to the CRAC cooling coils. More efficient cooling systems employ low outside air temperatures to reduce chiller load. Cooling towers that use ambient air to directly cool or precool the chilled water are known as water-side or fluid-side economizers. This type of system has been claimed to cut cooling-energy costs by as much as 70% (ASHRAE HVAC Fundamentals Handbook 2005) during economizer operation. Based on local weather data in San Jose, water-side economizers can be used for more than one-third of the year (PG&E 2006). An alternate data center arrangement uses air-handling units (AHU) and an air-side economizer. Such systems directly provide outdoor air for cooling whenever the temperature of outside air is lower than the set-point for return-air temperature in the data center. In San Francisco's cool climate, outside air could contribute to some level of air-side cooling for nearly all hours of the year (Syska Hennessy 2007). The use of air-side economizers brings with it an associated concern about contamination including moisture from humidity that may possibly threaten equipment reliability. Deliquescent sulfate, nitrate and chloride salts, in a humid environment (> 40% relative humidity) can cause corrosion, accumulate and become conductive, and may lead to electrical short-circuiting (Rice et al. 1981; Sinclair et al. 1990; Litvak et al. 2000). In this paper, the energy implications of a data center using a CRAC system will be compared with alternative cooling systems using air-side or water-side economizers for five different California climate zones. The modeling results and discussion focus on understanding the energy implications for both type of economizers and their effectiveness in different climate zones. The equipment reliability concerns associated with air-side economizers are acknowledged to be important, but addressing it is beyond the scope of the present paper.

Methods

Data Center Design Scenarios

Energy-use simulations were performed for three different data center HVAC design scenarios (Figure 1). The baseline case considers a data center using conventional "computer room air conditioning" (CRAC) units. In this scenario, CRAC units are placed directly on the computer room floor. Air enters the top of a CRAC unit, passes across the cooling coils, and is then discharged to the underfloor plenum. Perforations in the floor tiles in front of the server racks allow the cool air to exit from the plenum into the data-center room. Fans within the computer servers draw the conditioned air upward and through the servers to remove equipment-generated heat. After exiting the backside of the server housing, the warm air rises and is transported to the intake of a CRAC unit. Most air circulation in the baseline scenario is internal to the data center. A small amount of air is supplied through a rooftop AHU to positively pressurize the room and to supply outside air for occupants. Cooling is provided by a water-cooled chiller plant. Refrigerant in the chillers is used to cool water through heat exchangers at the evaporator. The chilled water is then piped to the CRAC units on the data center floor. Waste heat from the chiller refrigerant is removed by water through heat exchangers in the condenser. Condenser water is piped from the cooling towers, which cools the water through interaction with the outside air. This baseline design is common to most mid- to large-size data centers (Tschudi et al. 2003; Rumsey 2005; Syska Hennessy 2007).

Figure 1. Schematic of Data Center Cooling Design Scenarios



Air and water flow schematic for the basecase and water-side economizer scenarios (above).
Air and water flow schematic for the air-side economizer scenario (below).

The water-side economizer (WSE) scenario assumes a CRAC unit layout similar to that of the baseline case, except that additional heat exchangers are installed between the condenser water in the cooling towers and the chilled water supplied to the CRAC units. Under appropriate weather conditions, the cooling towers can cool the condenser water enough to cool the chilled water in the CRAC units directly, without operating the chiller plant. The CRAC units and chiller plant are assumed to be the same as in the baseline scenario.

The air-side economizer scenario (ASE) requires a different type of air delivery than typically found in a data center with conventional CRAC units. AHUs are placed outside of the data center room, commonly on the rooftop, and air is then sent to and from the computer racks through ducts. A ducted air delivery system creates greater air resistance than a conventional